DETERMINANTS OF PIGEONS' WAITING TIME: EFFECTS OF INTERREINFORCEMENT INTERVAL AND FOOD DELAY

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Four pigeons performed on three types of schedules at short (i.e., 10, 30, or 60 s) interreinforcement intervals: (a) a delay-dependent schedule where interreinforcement interval was held constant (i.e., increases in waiting time decreased food delay), (b) an interreinforcement-interval-dependent schedule where food delay was held constant (i.e., increases in waiting time increased interreinforcement interval), and (c) a both-dependent schedule where increases in waiting time produced increases in interreinforcement interval but decreases in food delay. Waiting times were typically longer under the delay-dependent schedules than under the interreinforcement-interval-dependent schedules. Those under both-dependent schedules for 1 subject were intermediate between those under the other two schedule types, whereas for the other subjects waiting times under the both-dependent procedure were similar either to those under the delay-dependent schedule or to those under the interreinforcement-interval-dependent schedule, depending both on the subject and the interreinforcement interval. These results indicate that neither the interreinforcement interval nor food delay is the primary variable controlling waiting time, but rather that the two interact in a complex manner to determine waiting times.

Key words: interreinforcement interval, delay of reinforcement, waiting time, postreinforcement pause, key peck, pigeons

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Pigeons and rats wait under differential reinforcement schedules in which only waiting times (i.e., times between responses or from trial onset to the first response) meeting some minimum criterion are reinforced, as in differential reinforcement of low rate (e.g., Staddon, 1965) or differential reinforcement of long latency (e.g., Catania, 1970) schedules. Waiting is also engendered under schedules that do not explicitly involve differential reinforcement of waiting. These schedules include those providing a reinforcer periodically, such as fixed-interval (FI) and fixed-ratio (FR) schedules. These waiting times are called the postreinforcement pause (PRP), defined as the interval between delivery of the reinforcer (or the beginning of the ratio interval in cases where a timeout follows reinforcement) and the first response. Waiting times under the above schedules typically covary with the time between successive reinforcers (the interreinforcement interval or IRI; e.g., Felton & Lyon,

1966; Ferster & Skinner, 1957; Schneider, 1969; Shull, 1979). This relation has prompted several researchers to consider the IRI as the prime variable controlling the PRP (cf. Killeen, 1969; Nevin, 1973; Rider, 1980).

An alternative candidate for controlling PRP duration is not the IRI of which it is a part, but the part of the IRI following the PRP, which is known as the *response run* (e.g., Shull, 1979). Figure 1 portrays the relation between IRI, PRP (or waiting time), and response run (or delay of reinforcement). In Shull's account, the PRP is a by-product of the time occupied by the response run. Critical to initiation of the response run is the relation between the first response in the run and the time or response requirement to reinforcement, that is, the reinforcement delay. Longer PRPs occurring as the parameter of an FI or FR schedule is increased are associated not only with an increasing IRI but also increasing delays to reinforcement from the run-initiating response. Because the delay to reinforcement covaries with response rate or probability, the PRP might reflect control over responding by reinforcer delay.

Hence, the PRPs under FR and FI schedules can be attributed to either (a) the IRI, which is determined by times occupied by the PRP and the response run, (b) the duration of the response run (delay of reinforcement), which, given a steady response rate, is the com-
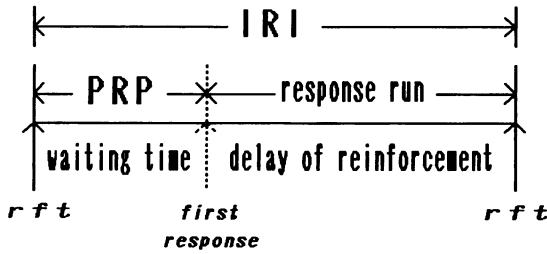
Fig. 1. The relation between IRI, PRP (or waiting time), and response run (delay of reinforcement). rft = reinforcement.

Fig. 2. The obtained interreinforcement interval (IRI) and the obtained delay of reinforcement as a function of PRP under FI and FR schedules.

plement of the PRP (cf. Capehart, Eckerman, Guilkey, & Shull, 1980; Shull, 1979), or (c) some combination of the two.

It is unlikely, however, that IRI or delay duration controls PRPs under FR and FI schedules in precisely the same way, because the inherent differential reinforcement of PRP under FR schedules is rather different from that under FI schedules. Under FR schedules, shorter PRPs are associated with higher reinforcer rates, because the obtained IRI decreases with decreases in the PRP as long as the response run is stable. Conversely, under FI schedules, longer PRPs are differentially reinforced by shorter delays to reinforcement, because the obtained delay decreases as the PRP approaches the FI value. The IRI and delay of reinforcement produced by various PRPs under FR and FI schedules are shown in Figure 2. Capehart et al. (1980) found that, at short IRIs (i.e., <40 s), PRPs were shorter under FR schedules than under FI schedules having similar IRIs. They concluded that FR schedules and FI schedules do not control PRP in the same way. Although they suggested that the primary variable controlling PRP was delay to reinforcement (they called it "work time"), this difference may result from differences in the two inherent differential reinforcement effects relating waiting time to IRI and delay of reinforcement under the two schedules. Further, Kelleher, Fry, and Cook (1959) found that an adjusting schedule (in which the FR size was varied as a function of the duration of the PRP) controlled the PRP. This finding could not be correlated independently with either changes in IRI or delay of reinforcement, however, because in their experiment both changed as the FR value was adjusted.

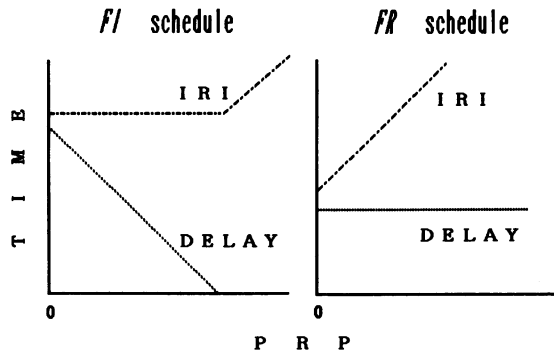One of the questions addressed by the pres-

ent experiment is whether, at short IRIs, only one variable, either delay of reinforcement or IRI, controls pigeons' waiting time (as previous accounts have asserted) or whether both contribute independently to the control of waiting. If both, then the question is whether IRI or delay of reinforcement is more powerful in controlling waiting time.

The logic of the present experiment is as follows. If the IRI and delay of reinforcement differentially control the waiting time under periodic food schedules, the waiting times under schedules in which the delay to reinforcement decreases with increasing waiting time while IRI is fixed (a delay-dependent schedule, of which an FI schedule is an example) should be longer than waiting times under schedules in which the delay to reinforcement is fixed and IRIs increase with increasing waiting time (an IRI-dependent schedule, of which an FR schedule is an example, given a roughly constant run duration). This is because the pause-dependent change in IRI keeps waiting times short under the latter schedule, whereas the shorter delay of reinforcement associated with longer waiting times under the former schedule may differentiate longer PRPs. Waiting times under schedules in which increasing waiting times increase the IRI but decrease reinforcement delay (a both-dependent schedule) may be intermediate between those under an IRI-dependent schedule and those under a delay-dependent schedule, because the two effects may counteract each other. An example of the functions relating IRI and reinforcement delay to waiting time under this type of adjusting schedule is shown in Figure 3. In contrast, if pigeons are more sensitive to

the effects of IRI, the waiting times under the both-dependent schedule should more closely resemble those under the IRI-dependent schedule. If pigeons are more sensitive to the differential reinforcement associated with delay of reinforcement, the waiting times under the both-dependent schedule should approximate those under the delay-dependent schedule. Waiting times under the both-dependent schedules, therefore, may permit the assessment of the relative power of the two factors that control waiting times.

To this end, the present experiments arranged the following schedules: (a) the IRI depended on the waiting time (IRI-dependent schedule); (b) the delay to reinforcement depended on the waiting time (delay-dependent schedule); and (c) both the IRI and the reinforcement delay depended on the waiting time (both-dependent schedule). Under the IRI-dependent schedule, the IRI increased as waiting time increased, because the delay to reinforcement was fixed. This contingency is roughly analogous to that under an FR schedule. Under the delay-dependent schedule, the delay to reinforcement decreased with increasing waiting times, because the IRI was fixed (provided the waiting time was shorter than the IRI). This contingency is analogous to that under an FI schedule. Under the both-dependent schedule, an increase of the waiting time increased the IRI but decreased the delay to reinforcement. This contingency was carried out by means of adjusting the delay of reinforcement according to the duration of the current waiting time. This contingency is analogous to that under an interlocking schedule (e.g., Ferster & Skinner, 1957). To eliminate the effects of response cost, only one response was required under each of these schedules.

METHOD

Subjects

Four adult male homing pigeons were maintained at 80% of their free-feeding weights. The birds had free access to grit and water in their home cages.

Apparatus

One sound-attenuating experimental chamber was used. The dimensions of the chamber were 30 cm by 31 cm by 30 cm. The response key was located behind a 2-cm-diameter hole

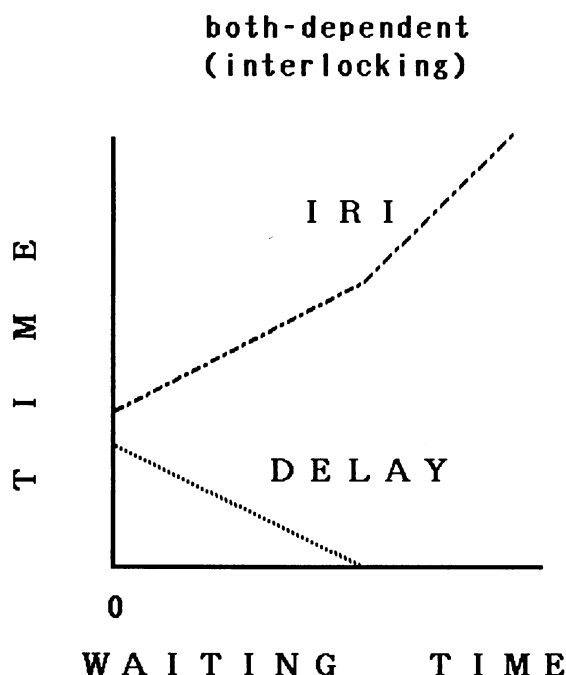**both-dependent (interlocking)**

Fig. 3. The obtained interreinforcement interval (IRI) and the obtained delay of reinforcement as a function of waiting time under a both-dependent schedule.

20 cm from the floor. A force of approximately 0.15 N activated a microswitch behind this key and recorded a response. The key could be transilluminated by a red light. Beneath the response key was a food hopper that contained grain. Reinforcers were 3-s periods of access to this grain. White noise and the sound of a ventilating fan masked extraneous sounds. A microcomputer, located in an adjacent room, controlled all experimental conditions and data collection.

Procedure

Because all birds had previous exposure to a variety of reinforcement schedules, no preliminary training was necessary. To minimize the effects of eating on pausing, a 2-s blackout was inserted after each reinforcer. At the beginning of each trial, the key was transilluminated by a red light. A simple response to the key initiated the delay interval, during which the chamber was totally dark.

Initially, all birds performed on a both-dependent schedule (technically speaking, an interlocking schedule). Under this schedule, the initial response turned off the keylight and

Table 1

Median waiting times, standard deviations, obtained median IRIs, obtained median delays of reinforcement, and the number of training sessions arranged for each condition. The order of schedules is shown from top to bottom. Data are based on the last nine sessions.

Subject	Schedule	Waiting time (SD) (s)	IRI (s)	Delay (s)	Sessions
8520	both-dependent ($T = 10$ s)[a]	5.5 (0.8)	9.8	2.3	23
	IRI-dependent	2.2 (0.5)	6.5	2.3	20
	delay-dependent	5.3 (0.8)	9.8	2.5	29
	both-dependent ($T = 30$ s)[a]	17.9 (2.7)	25.9	6.1	50
	delay-dependent	18.8 (1.3)	25.9	5.1	22
	IRI-dependent	4.0 (0.5)	12.1	6.1	34
	both-dependent ($T = 30$ s)[a,b]	13.2 (3.1)	23.6	8.4	18
	both-dependent ($T = 60$ s)[a]	41.0 (5.7)	52.5	9.5	44
	delay-dependent	34.7 (5.9)	52.5	15.8	23
	IRI-dependent	6.4 (0.8)	17.9	9.5	23
	both-dependent ($T = 60$ s)[a,b]	31.4 (6.5)	47.7	14.3	29
	IRI-dependent[b]	7.7 (0.9)	24.0	14.3	33
	yoked delay	3.9 (2.8)	20.2	14.3	50
	yoked IRI	30.5 (3.2)	47.7	15.2	26
	both-dependent ($T = 60$ s)[a,b]	42.0 (14.1)	53.0	9.0	50
8524	both-dependent ($T = 10$ s)[a]	1.4 (0.1)	7.7	4.4	24
	delay-dependent	2.1 (0.3)	7.7	3.6	18
	IRI-dependent	1.0 (0.2)	7.4	4.4	47
	both-dependent ($T = 30$ s)[a]	3.0 (0.5)	18.5	13.5	43
	delay-dependent	5.4 (1.1)	18.5	11.1	42
	IRI-dependent	4.2 (0.4)	19.7	13.5	50
	both-dependent ($T = 30$ s)[a,b]	5.3 (1.0)	19.6	12.3	45
	IRI-dependent[b]	6.3 (1.4)	20.6	12.3	31
	yoked IRI	5.9 (0.5)	19.6	11.7	50
	yoked delay	4.0 (0.4)	18.3	12.3	25
	both-dependent ($T = 30$ s)[a,b]	4.5 (0.7)	19.3	12.8	19
	both-dependent ($T = 60$ s)[a]	21.7 (1.9)	42.9	19.2	46
	IRI-dependent	8.0 (1.6)	27.2	19.2	40
	delay-dependent	11.3 (1.3)	42.9	29.6	23
	both-dependent ($T = 60$ s)[a,b]	10.2 (2.8)	37.1	24.9	24
8601	both-dependent ($T = 10$ s)[a]	0.7 (0.1)	7.3	4.7	25
	IRI-dependent	0.4 (0.1)	7.1	4.7	22
	delay-dependent	0.5 (0.1)	7.3	4.8	21
	both-dependent ($T = 30$ s)[a]	4.4 (0.7)	19.2	12.9	50
	delay-dependent	6.0 (0.5)	19.2	11.2	23
	IRI-dependent	1.7 (0.2)	16.6	12.9	36
	both-dependent ($T = 30$ s)[a,b]	2.2 (0.3)	18.1	13.9	22
	both-dependent ($T = 60$ s)[a]	9.4 (2.2)	36.7	25.3	50
	delay-dependent	15.3 (2.8)	36.7	19.4	33
	IRI-dependent	5.8 (1.1)	33.1	25.3	50
	both-dependent ($T = 60$ s)[a,b]	6.5 (0.7)	35.2	26.7	24
	IRI-dependent[b]	5.9 (0.9)	34.6	26.7	44
	yoked IRI	13.9 (1.2)	35.2	20.7	35
	yoked delay	3.6 (0.6)	32.3	26.7	50
	both-dependent ($T = 60$ s)[a,b]	5.9 (0.6)	34.9	27.0	48
8605	both-dependent ($T = 10$ s)[a]	2.0 (0.3)	8.0	4.0	48
	delay-dependent	2.0 (0.2)	8.0	4.0	28
	IRI-dependent	1.5 (0.3)	7.5	4.0	50
	both-dependent ($T = 30$ s)[a]	6.6 (1.6)	20.3	11.7	46
	delay-dependent	8.9 (1.0)	20.3	9.4	28
	IRI-dependent	4.1 (0.7)	17.8	11.7	35
	both-dependent ($T = 30$ s)[a,b]	7.1 (0.5)	20.6	11.5	33
	IRI-dependent[b]	3.9 (0.5)	17.4	11.5	34
	yoked delay	3.0 (0.5)	16.5	11.5	32
	yoked IRI	12.3 (1.3)	20.6	4.3	46
	both-dependent ($T = 30$ s)[a,b]	5.5 (1.2)	19.8	12.3	44

Table 1 (*Continued*)

Subject	Schedule	Waiting time (*SD*) (s)	IRI (s)	Delay (s)	Sessions
	both-dependent (*T* = 60 s)[a]	8.2 (0.6)	36.1	25.9	25
	IRI-dependent	6.5 (0.6)	34.4	25.9	21
	delay-dependent	18.0 (2.6)	36.1	16.1	26
	both-dependent (*T* = 60 s)[a,b]	11.0 (1.9)	37.5	24.5	18

[a] Both-dependent schedule: the delay was determined in accordance with the term $0.5(T - X)$; where X indicates the waiting time and T is a constant specified by the experimenter.

[b] Redetermination.

started the delay timer. A reinforcer was presented automatically at the end of the delay. The delay duration was prolonged by 0.5 s for every 1 s the waiting time was below a certain value (*T*). When the waiting time was greater than *T*, the response was reinforced immediately. (This contingency results in the functions relating IRI and reinforcement delay to waiting time that are depicted in Figure 3.) With this contingency, increasing waiting time decreases the delay of reinforcement but increases the IRI for all waiting times below *T*. Values of *T* examined were 10, 30, and 60 s in different conditions. Subsequently, the birds performed on a delay- and an IRI-dependent schedule. The delay-dependent schedule was a conjunctive FR 1 fixed-time (FT) schedule, and the IRI-dependent schedule was a chain FR 1 FT schedule. Under the delay-dependent schedule, the duration of the delay (FT value) was adjusted to produce a fixed IRI that was the same as the obtained mean of median IRIs in the last nine sessions of the both-dependent schedule. When the waiting time exceeded the FT, the response was reinforced immediately. This procedure resulted in IRIs and delays to reinforcement produced by various waiting times like those shown in the left of Figure 2. Under the IRI-dependent schedules, the delay to reinforcement was fixed. The duration of the delay was the same as the obtained mean of median delay in the last nine sessions of the both-dependent schedule. The IRIs and associated delays produced by various waiting times in the IRI-dependent schedule are those shown in the right of Figure 2. All subjects were exposed to these schedules in the order just described, first with *T* = 10 s, then 30 s, then 60 s. When *T* equaled 30 s and 60 s, subjects were returned to the both-dependent schedule after exposure to the IRI- and the

delay-dependent schedules. The sequence of conditions for each bird is shown in Table 1.

Additional conditions were conducted to examine the effects of variability of IRI and delay of reinforcement on waiting time. After completing the both-dependent schedule, subjects performed under two yoked-control conditions, namely a yoked-delay condition and a yoked-IRI condition. Under the yoked-delay condition, the first response in the trial produced the same individual delay obtained during one of the last nine sessions of the both-dependent schedule. Under the yoked-IRI condition, the delay was adjusted to produce the same individual IRI obtained during one of the last nine sessions in the both-dependent schedule. If the waiting time was greater than the IRI, the response was reinforced immediately. The yoked-control sessions were divided into successive blocks of nine sessions. The individual delays or individual IRIs of the first session of a block were the same as those of the ninth from the last session of the both-dependent schedule, the second the eighth from the last, the third the seventh from the last, and so on. Subjects 8524 and 8605 performed under conditions yoked with the *T* = 30 s both-dependent schedule, and Subjects 8520 and 8601 performed under those yoked with the *T* = 60 s both-dependent schedule (see Table 1).

All subjects received one session daily, 6 days per week. Each session terminated after 40 reinforcers had been delivered. The hopper light and keylight were the only sources of illumination in the chamber. All conditions were continued until the median waiting time or the number of sessions satisfied the following criterion: after 18 sessions, the last nine were divided into three successive blocks of three. The waiting time was considered stable when the mean of medians of three blocks did
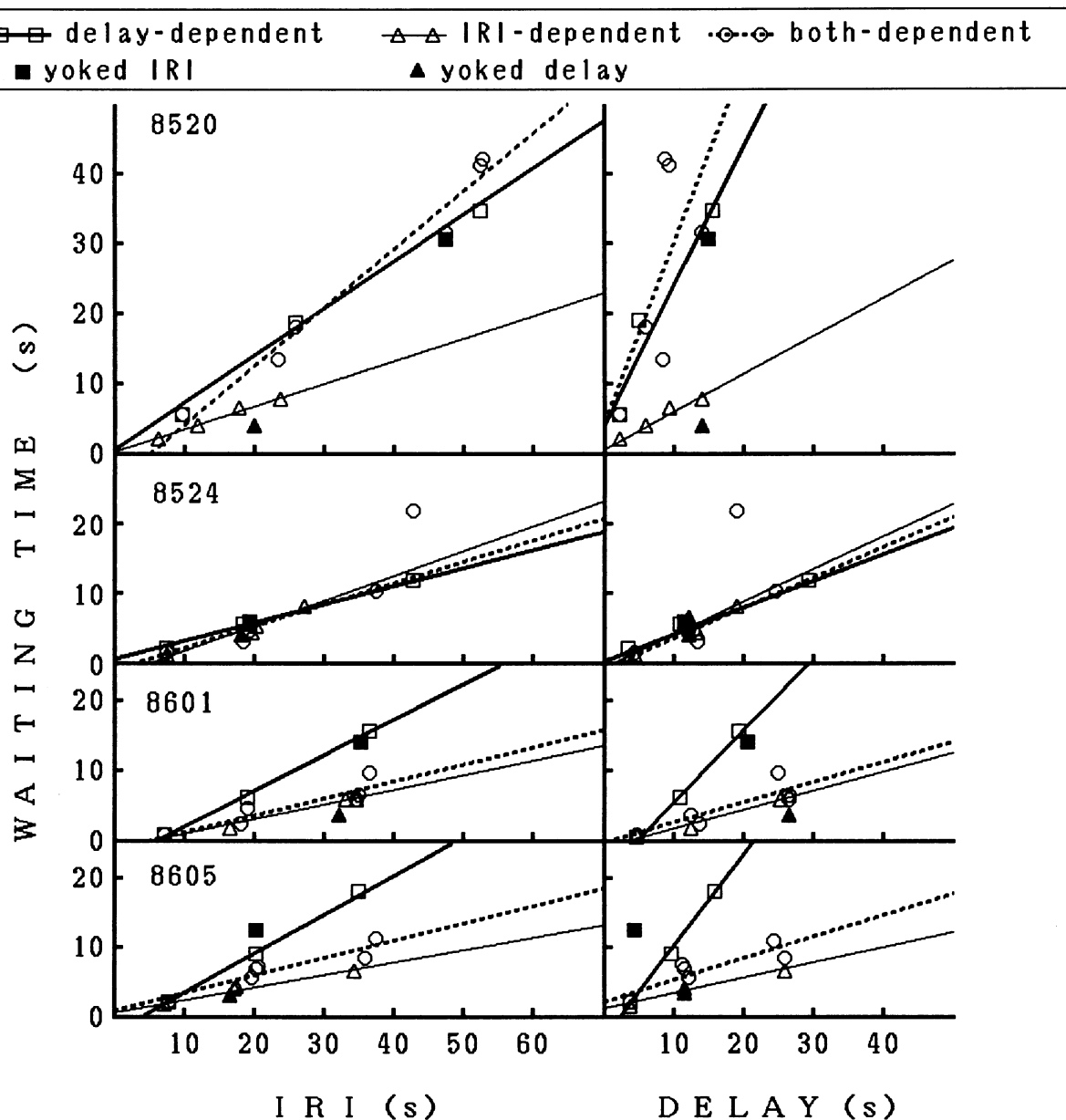
Fig. 4.   Median waiting time as a function of obtained interreinforcement interval (left half) or obtained delay of reinforcement (right half). The open circles indicate the median waiting times under the both-dependent schedule, open triangles those under the IRI-dependent schedule, and open squares those under the delay-dependent schedule. The closed symbols indicate those under the yoked-control conditions. Data are shown for $T = 10$ s, 30 s, and 60 s.

not differ from each other by more than 5%, and there was neither an upward ($M1 > M2 > M3$) nor a downward ($M1 < M2 < M3$) trend in the block means. Training continued under this stability criterion for a maximum of 50 sessions.

RESULTS

Table 1 shows means of the median waiting times, the standard deviation of the waiting time, the mean of the median obtained IRIs, and the mean of the median obtained delays

Table 2

The coefficients of determination (r^2) and the corresponding least squares linear regression equations for the three schedules.

Subject	X	Delay-dependent (r^2)	IRI-dependent (r^2)	Both-dependent (r^2)
8520	IRI	$Y = 0.68X - 0.38$ (0.99)	$Y = 0.32X + 0.18$ (0.99)	$Y = 0.83X - 4.18$ (0.97)
	delay	$Y = 2.00X + 4.00$ (0.92)	$Y = 0.54X + 0.44$ (0.98)	$Y = 2.55X + 4.08$ (0.97)
8524	IRI	$Y = 0.26X + 0.32$ (0.99)	$Y = 0.35X - 1.75$ (0.94)	$Y = 0.31X - 1.39$ (0.95)[a]
	delay	$Y = 0.38X + 0.27$ (0.98)	$Y = 0.46X - 0.82$ (0.87)	$Y = 0.43X - 0.94$ (0.89)[a]
8601	IRI	$Y = 0.51X - 3.38$ (0.99)	$Y = 0.21X - 1.37$ (0.99)	$Y = 0.24X - 1.17$ (0.85)
	delay	$Y = 1.02X - 4.76$ (0.99)	$Y = 0.27X - 1.19$ (0.97)	$Y = 0.29X - 0.54$ (0.75)
8605	IRI	$Y = 0.57X - 2.60$ (0.99)	$Y = 0.18X + 0.52$ (0.97)	$Y = 0.25X + 0.85$ (0.87)
	delay	$Y = 1.32X - 3.38$ (0.99)	$Y = 0.22X + 1.10$ (0.95)	$Y = 0.31X + 2.11$ (0.77)

[a] A deviating data point was omitted in the calculation.

of reinforcement, determined for each subject during the last nine sessions of each condition.

Figure 4 shows the mean of the median waiting time during the last nine sessions of each condition as a function of the mean of the obtained median IRI (left half) and the mean of the obtained median delay of reinforcement (right half) under the three schedule types and under the yoked-control conditions. The lines were derived by the method of least squares relating waiting time to IRI and delay of reinforcement for the delay-dependent schedule (bold line), the IRI-dependent schedule (thin line), and the both-dependent schedule (dashed line), respectively. The means of the median waiting times under all schedules were increasing functions of the IRI and the delay of reinforcement. Waiting times typically were longer under delay-dependent schedules than under IRI-dependent schedules having similar IRI and similar delay of reinforcement, except for Subject 8524, whose waiting times were similar under the three schedule types.

Waiting times under the both-dependent schedule were almost the same as those under the delay-dependent schedule for Subject 8520. In contrast, those for Subject 8601 were almost the same as those under the IRI-dependent schedule. For Subject 8605, waiting times were intermediate between those under the delay-dependent schedule and under the IRI-dependent schedule. For Subject 8524, the three lines did not differ. The waiting times under yoked-delay and yoked-IRI conditions fell in the vicinity of the functions for IRI-dependent and delay-dependent schedules, respectively (see Figure 2).

The coefficients of determination (r^2) and the corresponding least squares linear regres-

sion equations are shown in Table 2. The slopes of the linear regression lines relating waiting time to IRI under delay-dependent schedules were almost 0.6, a value observed frequently in several FI schedules (Dukich & Lee, 1973; Schneider, 1969; Shull, 1971). On the other hand, slopes under IRI-dependent schedules were considerably smaller for 3 of the 4 birds. A similar tendency was observed in the slope of the linear regression lines relating waiting time to reinforcement delay. The r^2 values under the both-dependent schedule ranged from .75 to .97, whereas the r^2 values under the other schedules were greater than .90 in all but one case. This indicates that the waiting times under the three schedules were almost linearly related to the obtained IRI and the obtained delay of reinforcement.

Because the chamber was totally dark during the delay, the mean frequencies of responses during each delay interval were less than one under each schedule for each subject.

DISCUSSION

Waiting times typically were shorter under the delay-dependent schedules than under the IRI-dependent schedule having similar IRIs and similar delay of reinforcement. The present results are consistent with those of Capehart et al. (1980) at short IRIs. They found that PRPs differed under FR and FI schedules having similar IRIs. However, the present results are inconsistent with those of Wynne and Staddon (1988), where waiting times did not differ between two schedules that were comparable to the present IRI- and delay-dependent schedules. They exposed pigeons to each schedule for only six to eight sessions. In con-

trast, pigeons in the present experiment were trained for 18 to 50 sessions. Thus, the number of training sessions may be critical to this inconsistency. This argument is supported by the following analysis: Although the slopes under the delay-dependent schedule in the present experiment were almost the same as those obtained typically under FI schedules in which subjects were usually trained 30 or more sessions, those in the experiment of Wynne and Staddon were shallower than those typically obtained under FI schedules. In addition, the slopes obtained in Experiment 2 of Wynne and Staddon were steeper than in their Experiment 1 (Experiment 2 was performed after completing Experiment 1 and used the same subjects). These observations suggest that differential waiting times may occur only after long exposure to a schedule.

Although the r^2 values for the functions relating waiting times and the obtained IRI were a little larger than those for the functions relating waiting times and the obtained delay of reinforcement, this does not necessarily indicate that the obtained IRI is the primary controlling variable of waiting time. The obtained IRI is the sum of the waiting time and the delay of reinforcement under these schedules. Therefore, the r^2 for the function between the waiting times and the obtained IRI should be greater than or equal to that for the function between the waiting times and the obtained delay of reinforcement, even when only the obtained delay of reinforcement determines waiting time.

Under the both-dependent schedule, an increase in waiting time decreased the delay of reinforcement but increased the IRI. This schedule put control by IRI and delay of reinforcement in opposition. Under the both-dependent schedule, waiting times for Subject 8520 were almost the same as those under the delay-dependent schedule. Conversely, waiting times for Subject 8601 were almost the same as those under the IRI-dependent schedule. This result indicates that Subject 8520 was differentially sensitive to delay of reinforcement, whereas Subject 8601 was more sensitive to the changes in the IRI.

A different result was observed for Subject 8605. The waiting times under the both-dependent schedule were intermediate between those under the delay-dependent schedule and those under the IRI-dependent schedule. This result implies that the two effects may counteract each other on the waiting times under the both-dependent schedule, because the decreasing IRI decreased the waiting times whereas the decreasing reinforcement delay would have acted to reinforce differentially long waiting times. Subject 8605 may have shown sensitivity to each source of control under the both-dependent schedule.

Waiting times under the yoked conditions were similar to both the IRI-dependent or delay-dependent schedules. Although the IRI or delay to reinforcement was variable under the yoked conditions, the relations between waiting time and IRI or between waiting time and delay to reinforcement still remained (increasing waiting time increased the current IRI under the yoked-delay conditions and decreased the current delay to reinforcement under the yoked-IRI conditions). Under the both-dependent schedules, the standard deviations of obtained IRI or of obtained delay to reinforcement were half that of waiting time as long as the waiting time was shorter than T. This is because increasing waiting time by some value (e.g., 10 s) decreased the delay to reinforcement by only half that amount (e.g., 5 s), thereby increasing the IRI by only 5 s. Therefore, the obtained IRI and obtained delay to reinforcement should be fairly stable under the both-dependent schedules. Thus, the contingencies under yoked conditions based on the obtained IRI or the obtained delay to reinforcement under both-dependent schedules would be similar to that of IRI-dependent or that of delay-dependent schedules. This stability of IRI and delay to reinforcement might result in the similarity of waiting times between the yoked conditions and IRI-dependent or delay-dependent schedules.

From the viewpoint of maximizing or optimality, Shull (1979) showed that the optimal mean waiting time is about half the IRI under an FI schedule, which is comparable to the delay-dependent schedule in the present experiment. A mean waiting time of this length distributes almost all responses below the IRI, thereby not prolonging the IRI while minimizing the reinforcement delay. Although the present data are based on the medians, the results under the delay-dependent schedule were consistent with this prediction. Shull suggested that IRI dependence also controls the waiting time under a delay-dependent sched-

ule. In contrast, under IRI-dependent schedules, the waiting time should be minimal in order to minimize the IRI, because the delay to reinforcement is fixed. However, the waiting times under the IRI-dependent schedule in the present experiment increased with increases in IRI and delay to reinforcement. Such a result is comparable to the PRP increasing with increases in FR values (cf. Felton & Lyon, 1966). The optimal prediction of Shull was not confirmed, therefore, even when there was no response requirement during the delay interval.

Previous accounts have asserted that waiting time is controlled primarily by one variable (cf. Capehart et al., 1980; Killeen, 1969; Nevin, 1973; Rider, 1980; Shull, 1979; Wynne & Staddon, 1988). The present results support the alternative argument that each of the two sources of control, IRI and delay of reinforcement, are important factors controlling waiting times.

Capehart et al. (1980), however, suggested that the two types of schedule contingencies differentially control only the measured terminal behavior and that the primary controlling variable is the "work time," which includes both unmeasured and measured work times. (Their work time is comparable to the delay of reinforcement in the present study.) They asserted that FR schedules keep the unmeasured terminal behavior (e.g., positioning oneself before the response key and/or pecking with insufficient force to switch the microswitch) short, and that FI schedules are ineffective in shortening such behavior. Therefore the first measurable responses (PRPs) under FR schedules occur at earlier times in the IRI than those under FI schedules. However, if the unmeasured terminal behavior is the critical factor causing the difference in waiting times between the two schedules, then the unmeasured behavior would have to consume between 8 s and 26 s under the present schedules at a 15-s delay of reinforcement, because those were the differences in waiting time between the present schedules at a 15-s delay of reinforcement. It is difficult to believe that unmeasured terminal behavior would consume such a long duration. Further, Rider and Kametani (1984) suggested that unmeasured terminal behavior consumes a fairly constant amount of time in each IRI. Thus, the difference in waiting time between IRI- and delay-dependent schedules is not likely to be caused primarily by the shortened unmeasured terminal behavior under IRI-dependent schedules.

Another question addressed by the present experiments is whether differential reinforcement by IRI dependence or by delay dependence is more powerful in controlling waiting time. Under the both-dependent schedule, the waiting time for Subject 8520 appeared to be controlled almost solely by the differential delay of reinforcement, whereas the waiting time for Subject 8601 appeared to be controlled by the differential IRI, as judged by the similarity of the slopes in the regression lines between the both-dependent, IRI-dependent, and delay-dependent conditions. The intermediate slope obtained under the both-dependent schedule for Subject 8605 suggests that waiting time might have been affected by both sources of control. These results seem to indicate that there are large individual differences in subjects' sensitivities to these two sources of control over waiting times. These extreme differences among subjects may be caused by the following: (a) The control by IRI or reinforcement delay is a step function, with different subjects shifting from one source of control to another at different points, or (b) the control by two sources may combine in a more continuous fashion. A test of these two arguments may be possible. If the additional delay for every 1 s the waiting time is below T is gradually increased to 1 s from 0.5 s, the schedule increasingly becomes a delay-dependent schedule. Conversely, if the additional delay is gradually decreased to 0 s from 0.5 s, then the schedule approaches an IRI-dependent schedule. Thus, the two functions of IRI- and delay-dependent schedules (presented in Figure 2) can be considered the extremes of a family of curves, of which the both-dependent schedule used here represents the midpoint. If the control by IRI and reinforcement delay is a step function, the waiting times under modified both-dependent schedules having longer additional delays than under the present both-dependent schedule should at some point abruptly jump to ones comparable to those obtained under the delay-dependent schedule. Conversely, if control by IRI and reinforcement delay combine continuously, waiting times under modified both-dependent schedules may fall on lines with slopes intermediate

between those obtained under the both-dependent schedule and those obtained under the delay-dependent schedule. Examination of more members of this family of schedules may provide better understanding of this differential sensitivity of waiting times to these two sources of control.

REFERENCES

Capehart, G. W., Eckerman, D. A., Guilkey, M., & Shull, R. L. (1980). A comparison of ratio and interval reinforcement schedules with comparable interreinforcement times. *Journal of the Experimental Analysis of Behavior, 34*, 61–76.

Catania, A. C. (1970). Reinforcement schedules and psychophysical judgments: A study of some temporal properties of behavior. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules* (pp. 1–42). New York: Appleton-Century-Crofts.

Dukich, T. D., & Lee, A. E. (1973). A comparison of measures of responding under fixed-interval schedules. *Journal of the Experimental Analysis of Behavior, 20*, 281–290.

Felton, M., & Lyon, D. O. (1966). The post-reinforcement pause. *Journal of the Experimental Analysis of Behavior, 9*, 131–134.

Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement.* New York: Appleton-Century-Crofts.

Kelleher, R. T., Fry, W., & Cook, L. (1959). Interresponse time distribution as a function of differential reinforcement of temporally spaced responses. *Journal of the Experimental Analysis of Behavior, 7*, 91–106.

Killeen, P. (1969). Reinforcement frequency and contingency as factors in fixed-ratio behavior. *Journal of the Experimental Analysis of Behavior, 12*, 391–395.

Nevin, J. A. (1973). The maintenance of behavior. In J. A. Nevin & G. S. Reynolds (Eds.), *The study of behavior: Learning, motivation, emotion, and instinct* (pp. 201–236). Glenview, IL: Scott, Foresman.

Rider, D. P. (1980). Alternative fixed-ratio fixed-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 33*, 243–252.

Rider, D. P., & Kametani, N. N. (1984). Interreinforcement time, work time, and the postreinforcement pause. *Journal of the Experimental Analysis of Behavior, 42*, 305–319.

Schneider, B. A. (1969). A two-state analysis of fixed-interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior, 12*, 677–687.

Shull, R. L. (1971). Sequential patterns in post-reinforcement pauses on fixed-interval schedules of food. *Journal of the Experimental Analysis of Behavior, 15*, 221–231.

Shull, R. L. (1979). The postreinforcement pause: Some implications for the correlational law of effect. In M. D. Zeiler & P. Harzem (Eds.), *Advances in analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour* (pp. 193–221). Chichester, England: Wiley.

Staddon, J. E. R. (1965). Some properties of spaced responding in pigeons. *Journal of the Experimental Analysis of Behavior, 8*, 19–27.

Wynne, C. D. L., & Staddon, J. E. R. (1988). Typical delay determines waiting time on periodic-food schedules: Static and dynamic tests. *Journal of the Experimental Analysis of Behavior, 50*, 197–210.